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THE FUTURE OF THE LAKE SUPERIOR DISTRICT AS AN IRON-ORE PRODUCER

BY

EDWARD W. DAVIS



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THE FUTURE OF THE LAKE SUPERIOR DISTRICT
AS AN IRON-ORE PRODUCER

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In the past, a very large proportion of the iron ore used in the United States and in the world has been secured from the Lake Superior iron mining district. Production has been at an enormous rate, and the question naturally arises as to how much longer this district can continue to supply the demand. A study of the situation brings out the encouraging fact that the district can continue to produce immense tonnages of iron ore for many centuries by utilizing its low-grade ore material. In a broad sense, low-grade ores may be said to include all material containing too small an amount of iron and too large amounts of non-ferrous minerals to be considered merchantable as mined. In addition to this, low-grade ore may also include material of acceptable iron content, but of such physical structure that it can not be used in the blast furnace. For the purpose of this discussion, low-grade iron ore may be considered as iron-bearing material that does not meet the present demands of the blast furnace operators and can not, therefore, be sold as mined.

CLASSIFICATION OF LOW-GRADE ORE MATERIALS

This general classification contains all non-merchantable ores and may be divided into several subdivisions. On the basis of iron content, they may be classified as follows:

1. Ores containing less than 40 per cent natural iron.
2. Ores containing between 40 and 50 per cent natural iron that are used to some extent at the present time as concentrating ores, or are mixed with ores of high iron content in order to increase the tonnage.
3. Ores containing over 50 per cent natural iron that are not in proper physical condition for blast furnace use.

In the first classification will be found the largest portion of low-grade ore material in the Lake Superior district. A much smaller amount of material will be found in the second classification and, comparatively, a very small amount of ore may be classified under the third division.

These ores may also be classified according to their structure. In the first group may be placed the ores of merchantable grades but not of merchantable structure. To this classification belong

the ores that are too fine or too coarse for furnace use in the condition in which they are mined. The fine ore must be agglomerated and the coarse ore must be crushed. In the second group may be classed the ores containing too much fine sand and other gangue material to be shipped direct, but in which the particles of gangue and iron oxide may be freed from each other by comparatively coarse crushing. To this class belong the ordinary wash ores, now being so largely utilized, as well as all material that can be concentrated at a coarse size by gravity concentration. In the third group may be classed the ores in which the gangue and the iron oxide are so intimately mixed that fine crushing is necessary in order to free the particles of iron oxide and gangue. To this class belong most of the altered taconites, and all of the unaltered taconites. This group contains by far the largest portion of low-grade ore in the Lake Superior district. In the fourth group may be classed ore material in which the iron is chemically combined with the gangue mineral and can not therefore be separated by mechanical means even after the very finest grinding. In this group may be classified the iron silicates and much of the paint rock.

AVAILABLE TONNAGE

The total amount of low-grade ore in the Lake Superior district is enormous. It has been variously estimated by ambitious geologists at from 30 billion tons to "enough to last the world a thousand years." No matter upon what basis the question is considered, it is evident that there is a sufficient amount of low-grade ore in the district to warrant a detailed study as to methods of utilization, and if methods of treatment can be developed by which this material may be utilized, a sufficient amount of ore is available to supply the demand for many generations.

Unfortunately, so little interest has been manifested in connection with this low-grade material, that much of the information regarding tonnage and quality that might now be available, has been lost. Thousands of feet of drill core have been thrown away, leaving no record other than the drillers' notation, "taconite." If all of these cores had been saved, tests could be made on them which would furnish priceless information for future guidance. The practice of destroying drill cores, especially if they show any evidence of the iron formation, should be discontinued. After sampling for assay, the cores should be carefully labeled and stored in some safe place, as it is impossible to secure in advance the

information pertaining to all of the important questions that may arise. Past experience proves that saving the drill core is the most satisfactory plan.

Having accepted the fact that there is an enormous amount of low-grade ore in the Lake Superior district, and having briefly discussed the grade and structure of this material, the next logical question to be considered is whether or not utilization will ever be necessary or possible.

THE NECESSITY FOR UTILIZATION OF LOW-GRADE ORE MATERIALS

It is, of course, recognized by everyone, that at some future date all of the merchantable ore will have been removed from the district. This date is placed by various estimators at from 15 to 30 years hence. This statement is based on the assumption that the present rate of shipment will continue until the end of the season of the last year. This, of course, can not be the case. The history of any successful mining district shows that during the first few years of life small tonnages of high-grade material are mined. As time passes and a district is more largely exploited, the tonnage mined each year increases. As the tonnage increases, the grade of the ore usually becomes lower. After a certain time, the yearly production of the district reaches a maximum and after the maximum is passed, the production gradually decreases. The rate of decrease in production is quite rapid at first, but absolute depletion of the district may not occur for a great many years. The history of the Lake Superior district will, undoubtedly, follow in a general way the history of most mining districts, and it is to be expected that some day, past or future, the district has reached, or will reach, the peak of its production. After the peak is passed, and it becomes generally recognized that the district is on a decline, the descent toward absolute depletion will be quite rapid.

The distribution of the Lake Superior ores among the various furnace companies shows that, while some companies have a sufficient supply of ore to last them 30 or 40 years, other companies have enough to last only 5 or 6 years. These companies are already looking about for new sources of ore supply, and if they are not to be found in the Lake Superior district the companies will go elsewhere. Serious attempts are already being made to bring the Cuban and South American ores into competition with the Lake Superior ores, and undoubtedly the furnace companies

that are expecting a shortage of ores will be only too glad to aid in the exploitation of new mining districts. When serious competition once starts against the Lake Superior district, production will, undoubtedly, decline rapidly. When this decline is generally recognized, it will not be as easy a matter to get new railroad equipment, new lake carriers, or new ore docks, as it has been in the past, and investors, realizing that the life of the district is limited to a few years, will hesitate to contribute more capital. This, in turn, will tend to reduce production further and to hasten the extinction of the district. It is a well-known fact that a mining district, once started on the down grade, gains impetus rapidly.

Whether or not one will admit that a serious situation now confronts the Lake Superior district, it is well to consider the iron-mining regions from which competition may be expected. In the May 3, 1919 issue of the *Engineering and Mining Journal*, an article appeared by Mr. Dwight Woodbridge, of Duluth, showing the cost per unit of iron for which ore can be delivered at valley points and at Atlantic ports from the various iron-mining districts of the world. These figures show that at valley points the Lake Superior district can deliver ore at a slightly lower cost per unit of iron than can its nearest competitors, which are Brazil, Newfoundland, Cuba, Sweden, and the mining districts of New York and New Jersey. All of these regions are on a fairly equal competitive basis, but the present shipping grades of Lake Superior ores can be delivered at valley points a little cheaper per unit of iron. These figures also show that at the Atlantic ports all of these other districts can deliver ore more cheaply than can the Lake Superior district, and if the grade of ore which the Lake Superior district can ship should decline a few per cent in iron content, the foreign ores could compete even at valley points.

Summing up the whole situation, it appears that very serious competition might exist at the present time, if it were not for the fact that the Lake Superior district is in actual operation on an immense and efficient scale as compared with competing districts. In other words, the strength of the position in which the Lake Superior district finds itself lies in the fact that it is now actually producing sufficient ore to supply the demand. Quoting from a recent publication by the Minnesota School of Mines Experiment Station: "The wonderful transportation systems, ore handling and dockage equipment, organizations and capital of the Lake Superior district are now available and ready to assist in prolon-

ing the life of the iron-ore industry. In this respect, the Lake Superior district has great advantage over many other mining regions, but capital is very mobile and railroads and docks can be allowed to deteriorate and as the future ore supply becomes more and more uncertain, this great advantage may gradually disappear."

Returning to the original question as to whether or not it will be necessary to utilize the low-grade ores of the Lake Superior district, it appears that it will not only be necessary to utilize these ores in order to maintain the production of the district, but it will be necessary to begin the utilization of them in the very near future. If the furnace companies that have only a few years' supply of ore available are allowed to invest large amounts of capital in developing and bringing into production new mining districts, the Lake Superior region will immediately start on its decline. If, on the other hand, these furnace companies find that the low-grade ores can be utilized, the fact that the Lake Superior district is already in large production and is so well equipped to handle immense tonnages will cause them to contemplate seriously investing new capital in this district for the purpose of developing the low-grade iron ores. The development of such an industry on a large scale will extend the life of the district into the far distant future.

Having arrived at the conclusions that the Lake Superior region has an almost inexhaustible supply of low-grade iron ore, that the utilization of this material is essential in order to maintain the production of the district, and that now is the time to start this low-grade iron-ore industry, the next logical question is, by what means may these low-grade ores be made useful.

METHODS BY WHICH LOW-GRADE ORE MATERIALS MAY BE MADE MERCHANTABLE

There are, in general, two factors that may make the utilization of the low-grade iron ores possible. These may be summed up as follows: First, a relative increase in the selling price of iron and steel, which will cause a readjustment in the schedule of iron-ore prices as determined by the Ore Buyers' Association, and second, a decrease in the present cost of producing iron and steel from these low-grade ores.

The possibilities offered by the first consideration seem to be slight. Any relative increase in iron and steel prices may come about only from an increase in demand that can not be met by

smelting only the so-called merchantable ores of the present time. Such a condition would make possible the utilization of a certain proportion of low-grade material. It must be remembered, however, that these conditions would bring several other iron-mining districts into strong competition with the Lake Superior region, and this district would receive only a portion of the benefit of the increase in price. For this reason, the holding of all the low-grade ore material as reserves of future shipping ore would eventually bring this material into such strong competition with ore from other districts that the Lake Superior low-grade deposits would probably never be utilized to any great extent. It seems, therefore, that the utilization of the Lake Superior low-grade ores through an increased demand caused by depletion of high-grade ores, thereby producing a readjustment in the iron-ore prices, should not be counted upon to make possible the utilization of the vast amount of low-grade material in this district.

The second possibility, namely, a decrease in the present cost of producing iron and steel from this low-grade ore material, should receive very serious consideration. In order to discuss this question intelligently, it is advisable to inquire into the present cost of producing iron in a blast furnace from low-grade ores.

REMOVAL OF SILICA FROM IRON ORES IN THE BLAST FURNACE

In a report recently made by J. R. Finlay to the director of the United States Bureau of Mines, considerable information is given which bears directly upon this subject. In considering the figures that appear in the above-mentioned report, deductions can be made, showing that for every increase of one unit of silica in the ore, the cost of producing a ton of pig iron, exclusive of the cost of the ore, increases about twenty cents. Therefore, if two tons of ore are required to make one ton of pig iron, the addition of one unit of silica to the ore increases the cost of smelting by about ten cents per ton. The freight on this additional one unit of silica is about two cents, and therefore the addition of one unit of silica to iron ore before shipment decreases its real worth by about twelve cents per ton. In a similar manner, it may be shown that the addition of 1 per cent moisture decreases the real worth of the ore by two cents per ton.

Certain modifications of these figures would be necessary in order to make them represent present conditions. Whether or

not the figures shown by Mr. Finlay and recast into the above form are exact, they give a fair basis on which to judge of the economic importance of removing the silica from low-grade ores before shipment. In order to produce a maximum increase in the real value of the ore, the silica should be removed before shipment, up to a point where its removal costs twelve cents per unit. Above this point, the silica can be removed more cheaply in the blast furnace. If the silica content of an ore can be reduced before shipment from 18 per cent to 8 per cent by mechanical means, one ton of the ore can be shipped and made into pig iron at a saving of \$1.20. If these ten units of silica can be removed from the ore mechanically at a total cost that is less than \$1.20 per ton, the ore should be treated and the silica removed before shipment.

It is then evident that before these low-grade ores should be smelted in a blast furnace, a large amount of the silica and moisture which they contain should be removed mechanically. This, and this only, will make possible the production of iron and steel at a price that will allow these ores to compete with the present grade of merchantable ores. Any reduction in freight rates or handling costs, or any improvement in iron and steel metallurgy will have the effect of raising the allowed limit of silica and moisture that shipping ores may contain, but it is difficult to conceive of any immediate improvement in smelting methods that will make possible a removal of a very large amount of silica from the ores by metallurgical means more cheaply than by mechanical means.

Considering the facts established, first, that this large tonnage of low-grade ore can be made valuable only by the removal of the moisture, silica, and other gangue material; second, that in order to prevent the Lake Superior district from gradually falling into decline these low-grade ores must be utilized, and third, that the initial steps toward developing the low-grade iron-ore industry should be taken immediately, the next question is, how can the gangue material and moisture be removed from these ores to such an extent and at such a cost that they can compete with the merchantable ores of the present time?

METHODS OF MECHANICAL CONCENTRATION OF LOW-GRADE ORE MATERIAL

A very large amount of careful investigative work has been done in perfecting the methods for removing the more valuable

metals and ores from their accompanying gangue minerals, but iron has been so relatively cheap and the deposits of usable ores have been so extensive and high grade that a comparatively small amount of attention has been given to the subject of ore-dressing as applied to iron ores. In attacking this problem, the natural tendency has been to use methods already developed in connection with other ore-dressing problems. There are certain marked characteristics of iron ores, however, that make the use of many of the already existing processes impossible. Many of the methods are too expensive to be considered. The tonnage to be handled is so large that most of the processes are entirely inadequate, and many of the machines already on the market are not properly designed for the treatment of iron-ore material.

A study of the methods that can cope with the problem of handling thousands of tons of hard iron ore daily at an extremely small operating and maintenance cost narrows the field, at the present time, to four processes. These may be classified under the heads of log-washing, table concentration, jigging, and magnetic concentration. Log-washing and table concentration, as originated in this district by the Oliver Iron Mining Company, are now in general use. Jigs are in use to a small extent, and the first plant in which magnetic concentration is to be attempted is now being built. Each of these four methods of treatment operate in connection with ores having certain definite characteristics which make them amenable to one or more of the concentration methods.

In order to effect any mechanical separation, it is first necessary to free the particles of mineral and gangue from each other. If they are chemically combined, mechanical separation is impossible, but fortunately, much of the low-grade ore in the Lake Superior district is only mechanically mixed with various impurities. In some cases, the mixture is very intimate and only the finest grinding will free the various minerals, while in other localities the ore is sufficiently broken when mined to make possible an effective separation. A brief consideration of each of the four methods of concentration may be advisable.

LOG-WASHING AND SCREENING

Log-washing and screening may be used only in case the ore can be concentrated at a relatively coarse size. Screening can not be economically carried on with material much finer than 8-mesh, and ordinary log-washing makes a separation at about 65-

mesh. The specific gravity of the mineral plays a relatively unimportant part in this method of separation, and concentration is made possible largely by the fact that the greater portion of the silica in the ore is mechanically free and quite fine, while the greater portion of the iron oxide is rather coarse. If there is any coarse gangue material in the ore it is not removed by screening or washing. If there is any fine iron oxide in the ore, a considerable portion of this is lost in the tailing from the washers. Washing and screening are admirably adapted to the treatment of certain classes of ores found in the Lake Superior district, and are probably the cheapest and simplest methods of concentration that will be devised.

JIGGING

Jigging has not been practiced to any great extent in Minnesota. In a few cases, jigs have been tried but later abandoned. The jig is a very useful machine in separating coarse particles of approximately the same size but of different specific gravities. In order to secure good jigging results, it is necessary to have an ore structure made up of clean bands or particles of iron oxide and gangue. If crushed to some size coarser than 10-mesh, the gangue should be practically liberated from the ore. In this case the jig when properly handled will produce a very satisfactory separation. The ordinary plunger type of jig was designed to operate on ores that contain a comparatively small amount of concentrate and a large amount of tailing. In adapting jigs to work upon iron ores, it should be remembered that these conditions are just reversed, that is, a comparatively large amount of concentrate is to be made, and a small amount of gangue material removed. The ordinary jig is not designed with this idea in view and, consequently, difficulty is often found in drawing off a large amount of clean concentrate at a rapid and uniform rate. Many of the failures in jigging iron ores have been due to the fact that the ores were not of the proper physical structure to make jigging successful. Jigging is a cheap and simple process of concentration only when relatively coarse crushing will practically free a large portion of the gangue. Any considerable quantity of middlings, that is, particles made up of both ore and gangue, makes the separation imperfect and the whole problem more complicated. If this middling product is combined with the concentrate it often increases the silica beyond an allowable limit, and if it is combined with the tailing the

iron loss is prohibitive. It is necessary in this case to re-crush the middling and prepare it for subsequent treatment.

The jig is a simple machine to construct and cheap to operate. The capacity is ordinarily large when operated on properly prepared jigging ore. For the best results, the fines should be removed from the ore before it is fed to the jig, and the coarser material should be divided into products of several sizes, each of which should be fed to separate jigs. One objection to the jig is that the products made are ordinarily accompanied by a large amount of water. This is especially true of the hutch product, which is the portion of the ore passing through the jig screens and drawn off through spigots in the bottom of the jig. Some form of mechanical dewaterer can be used to advantage in connection with the standard jigs.

In many of the so-called wash ores a certain amount of rather coarse rock is found. The coarsest of the gangue material may be more or less efficiently handpicked, but a large proportion of the rock between 1 inch and 65-mesh enters the log-washer or turbo concentrate. It is a comparatively simple matter to pass the coarse concentrates over jigs to remove the free siliceous material. In all probability, jigging will receive considerably more attention in the future in connection with the concentration of iron ores than it has in the past. It is a useful and efficient method of removing rocky material from the iron ores, and lends itself admirably to the solution of certain problems in the Lake Superior district.

TABLE CONCENTRATION •

Table concentration is used largely at the present time following the washing operations. Tables can treat successfully material finer than 4-mesh, but in order to secure good results the feed should be sized between narrow limits and each size should be treated separately. The fine slimes can not be successfully handled on tables, and if any considerable amount of iron is present finer than 200- or 300-mesh, it is usually lost in the tailing. The shape of the particles, as well as their specific gravities, plays an important part in determining whether or not table treatment will be efficient. Thin, flaky particles of heavy material, which lie flat on the table top, always tend to enter the concentrate, while rounded particles, which present a greater area to the current of water, are apt to be carried into the middling or even tailing. Some ores with fine mineral are, therefore, particularly adapted to table concentra-

tion, while others are not. In crushing specular hematite, the mineral tends to break into thin, flaky pieces, while the rock remains in more or less angular particles. A very efficient separation of this variety of ore can be effected by table concentration.

Table concentration will probably never be recognized as an important concentration process in the iron-ore industry until plants are built in which table treatment is the major operation. As long as tables are used simply as clean-up machines, they never will appear to their best advantage. The quality of the concentrate produced on tables is discounted by the furnace people because of its fine structure, the claim being that most of the ore blows out of the furnace and produces an abnormal amount of flue dust. The answer to this objection is that in a plant in which all or the major portion of the concentrate is produced on tables, the product should be agglomerated. Very desirable furnace products may be made by sintering, nodulizing, or briquetting the fine concentrate. A great objection to the use of tables is the relatively small capacity. On the other hand, the operating cost is extremely low and the successful solution of the problem may depend largely on the first cost of the plant and the interest on the investment.

MAGNETIC CONCENTRATION

The last method of treatment to be considered and the last to make its appearance in the Lake Superior district is magnetic concentration. This method of beneficiating iron ores has been in use for many years in New York State and Canada and some foreign countries, but, until recently, it has not been used in this district. A brief consideration of the working principles upon which this process is based may be instructive.

Magnetism is like the force of gravity and tends to make certain bodies move toward each other. Both magnetism and gravity vary according to the same laws, the chief difference being that the specific gravity of most material is greater than that of air while the magnetic permeability of most material is practically the same as that of air. Magnetism, like gravity, is a pure force and once put into existence requires no energy for its maintenance. When a weight is placed upon a table, it exerts a certain force against the top of the table and will continue to exert this force as long as it is not disturbed. Likewise, when a piece of iron is placed against a horseshoe magnet, it is held to the magnet by a certain force that will exist as long as the magnet is not disturbed.

It takes no more energy to maintain a magnetic field than it does to maintain the force of gravity, and, for this reason, the energy required to produce a separation of minerals by magnetic concentration is no greater than the energy necessary to produce a separation by log-washing, jigging, table treatment, or other forms of gravity concentration.

One strange characteristic of magnetism is that it may be made to exist to any considerable extent in only a comparatively few materials. These are called ferro-magnetic materials, and in this class may be placed the metals iron and nickel, and the minerals magnetite and franklynite. No satisfactory explanation can be given to this peculiarity, as it is not completely understood. For the purpose of this discussion, it is sufficient to say that magnetism is probably due to an arrangement of the atoms or molecules into forms that can be assumed by only a comparatively few materials. It is not due to a chemical change, and the magnetic properties of a material can no more be determined chemically than can color or hardness. In order to determine whether or not gravity concentration of any material is possible, specific gravity determinations may be made, and likewise, in order to determine whether or not magnetic concentration is possible, magnetic permeability determinations may be made.

With the above comparisons between magnetism and gravity in mind, it is easily understood that magnetic concentration offers a simple method for the separation of the few ferro-magnetic minerals. The iron oxide, magnetite, comes within this group and it is, therefore, a comparatively simple matter to remove the magnetite from an ore after it has been crushed sufficiently fine to free the particles of magnetite from the gangue.

Unfortunately, however, a large proportion of the low-grade ore found in the Lake Superior district is not magnetite but hematite, which is an oxide of iron that is not ferro-magnetic. Hematite, therefore, can not be easily concentrated magnetically. It is, however, possible to change hematite into magnetite by a very simple operation known as magnetic roasting. This process consists in heating the hematite to such a temperature and under such atmospheric conditions as will cause a small amount of the oxygen to be driven off. Pure magnetic oxide contains 72.4 per cent iron and 27.6 per cent oxygen, and pure hematite, the non-magnetic oxide, contains 70 per cent iron and 30 per cent oxygen. It is, therefore, necessary to remove 11 per cent of the oxygen

present in the hematite in order to change it into magnetic oxide. This would decrease the weight of the hematite by only 3.3 per cent. The process of magnetic roasting consists in heating the hematite ore to a temperature of from 400 to 600 degrees Centigrade, in the presence of a small amount of fuel such as fuel oil, soft coal, lignite, or possibly peat. The fuel produces reducing gases which remove the necessary amount of oxygen from the hematite and change it to the magnetic oxide. The process can be carried on in rotary kilns; and on a large scale in properly equipped plants, magnetic roasting can be accomplished rapidly and at a small cost. This roasting method of producing magnetic material from hematite is not at present in use to any considerable extent.

In considering magnetic concentration, as applied to the Lake Superior low-grade ores, there is a possibility of using this method of treatment in producing a merchantable product from the low-grade hematites, as well as from the magnetites. Since magnetic concentration can be carried on successfully with ore as coarse as 5-inch cubes and as small as the finest dust, it at once becomes apparent that this method of beneficiation is of great future importance and deserves considerable study.

Just as gravity concentrators are divided into several classes, depending upon the nature of the work, so magnetic concentrators take several different forms, in order to produce different results. Magnetic concentration has a great advantage over gravity concentration. This is due to the fact that the magnetic attraction can be easily varied between wide limits, while the attraction of gravitation always remains unchanged. This introduces a controllable variable into the process of magnetic concentration which is not found in gravity concentration, and which opens up many new possibilities.

When magnetism is applied to the separation of coarse material, the concentration process is usually carried on with the ore in a comparatively dry condition, and when applied to fine material carried on with the ore in a wet condition. The type of machine that is known as the drum cobber is generally used in the dry process. This machine is, in reality, a short belt conveyor, 6 or 8 feet in length, the head pulley of which is equipped on the inside with magnets. These magnets revolve with the pulley in one type of machine, and in the other type the magnets are held in a stationary position, allowing the surface of the pulley and the conveyor belt to revolve about them. The revolving magnet type

of cobber is used to make separation of material from 5-inch to 2-inch cubes. The stationary magnet type of cobber is used in making separations on material from 2-inch to 28-mesh. Neither of these types of machines operate satisfactorily on ores containing any considerable amount of material which will pass a 28-mesh screen.

In operating the magnetic cobber the ore is evenly distributed over the surface of the conveyor belt near the tail pulley. It is then carried by the belt to the magnetic head pulley, where the non-magnetic particles fall into one compartment beneath the machine, while the magnetic particles cling to the belt and are carried around to the under side of the drum and there fall into a separate compartment. The capacity of this type of machine is large, varying from 10 to 30 tons per hour depending upon the size of the particles and the nature of the separation desired. The belt is ordinarily 30 inches wide and travels at a speed of 200 feet per minute. The operating cost, as well as the first cost of this machine is very small and it is admirably adapted to the treatment of large quantities of hard rocky material. By adjusting the strength of the magnets, material of nearly any desired iron content may be separated from the rest of the ore.

As stated above, material finer than 28-mesh can not be satisfactorily treated on the drum cobber. There are several types of machines, however, that make a very efficient separation of magnetite ores which are crushed to 28-mesh or finer. The finer the ore is crushed, the better is the separation that can be made by the use of these machines. Several of these concentrators for finely pulverized ores take the form of magnetic drums, more or less completely submerged in water. Probably the machine of this class best known in the Lake Superior district is the one which has been called the magnetic log-washer. This machine, designed, built, and tested in the laboratories of the Minnesota School of Mines Experiment Station, is similar to an ordinary log-washer in construction with the exception that to the bottom of the tank of the washer is attached a series of magnets. These magnets tend to hold the magnetic material to the bottom of the trough, where the action of the logs forces the settled ore up the slope and delivers it as a clean concentrate, while the non-magnetic material is kept in agitation and is washed over the rear end of the machine as tailing. This machine is very simple and cheap

to operate, and the wear on the logs is much less than in ordinary log-washers, due to the fineness of the particles of ore which are treated.

There is available, then, simple, satisfactory apparatus of large capacity suitable for the concentration of magnetic ores. If a separation can be effected at some coarse size, no further treatment of the concentrate is necessary. If, however, it is necessary to crush the ore to some size finer than 28-mesh, the concentrate is usually produced wet and must be dewatered and agglomerated before it becomes desirable furnace product. The dewatering can be effected simply and rapidly by means of the continuous rotary filters. The product of these filters contains the amount of moisture necessary for agglomerating treatment which may be carried out by sintering, nodulizing, or briquetting. These processes of agglomerating are already in use by many of the furnace companies, in connection with the utilization of the flue dust which is made in the blast furnace. This agglomerated product is rapidly becoming recognized by the furnace operators as being far superior in structure to the majority of raw ore.

THE CONCENTRATION OF THE EAST MESABI MAGNETITES

The whole process of magnetic concentration as applied to the Eastern Mesabi magnetites is a good illustration of the manner in which the various types of machines can be made to work together so as to produce a high-grade furnace product from an ore material containing only 25 per cent of iron in the form of magnetite. The hard rock is first crushed to about 3-inch size and is then passed over a magnetic clobber. The field strength of this clobber is so adjusted that all of the coarse material containing no magnetic iron is discarded as tailing. The concentrate from this clobber is still too low grade to be useful, and is, therefore, crushed again to 2-inch size. This material is passed over a second clobber and the worthless gangue again discarded. This process of crushing, cobbing, and discarding worthless material continues until the product has been reduced to about $\frac{1}{4}$ -inch size. When this stage has been reached, approximately one half the ore has been discarded as tailing and the other half contains practically all of the magnetic oxide that was originally present in the rock. This $\frac{1}{4}$ -inch material, however, still contains too much gangue to be considered a desirable furnace product. It is, therefore, crushed

wet in ball mills until it will all pass a 100-mesh screen. This fine material is concentrated by magnetic log-washers in which the final separation is made. The concentrate produced by these machines is then dewatered by the use of continuous filters in the tank of which the fuel for sintering is mixed. The filter cake is conveyed directly to the sintering plant, where the ore is agglomerated. After being sintered the ore is screened in order to remove any fine material, and only the clean coarse sinter is shipped to the furnaces. It is apparent that in order to make this process a success financially, a large initial investment is necessary. The plant must be built in the most substantial manner, and only that machinery can be used which will operate efficiently and continuously under heavy loads and with little personal attention. At best, the profit per ton that can be made is small, and in order to make the proposition attractive financially, a plant of large capacity is necessary. While this process is a success, from the metallurgical point of view, its financial worth must yet be demonstrated.

The Mesabi Iron Company is now undertaking the last stage in the experiment, that is, the proving of the financial worth of the process. A plant is being built on the eastern end of the Mesabi Range, and it is hoped that within a year or two this plant will be in operation and will be contributing its share of ore to the yearly shipment from the district. It is extremely fortunate for the district and for the whole state that responsible individuals, who are willing to expend large sums of money in order to determine whether or not it is economically possible to produce a merchantable ore from this low-grade rock, have become interested in this problem. Any half-hearted attempt at the solution of this problem would have resulted in failure and would have been discontinued long ago. This is the first serious endeavor to utilize the really low-grade ores of this district, and if the experiment is successful, a remarkable stimulus will be given the low-grade iron-ore industry of the Lake Superior region.

As has been pointed out earlier in this discussion, now is the proper time to get this new industry under way. A great deal depends upon the success of this undertaking; possibly the whole future development of the district depends upon the success or failure of this particular attempt. If this undertaking proves successful, furnace companies looking for future ore supplies will be encouraged to secure them from the immense tonnages of low-

grade Lake Superior ores. In this case, the district is just now starting on a new era in its history, and great activities may be expected in the future in the low-grade iron-ore industry. On the other hand, if this undertaking by the Mesabi Iron Company proves to be unsuccessful, a great many years may pass before another serious attempt will be made to utilize the low-grade ores. In fact, if the previous conclusions in this discussion are correct, the failure of this first endeavor will probably cause the people in search of future ore supplies to look elsewhere, and the immense amount of low-grade ore available in this district may never be utilized.

It is apparent that the success or failure of this first attempt means much in the history of the Lake Superior region. Thoughtful men of the iron-mining industry are watching the progress which Mr. Jackling and his associates in the Mesabi Iron Company are making with the greatest interest. They recognize the fact that failure means a gradual decline of the district, while success means the awakening of a new period of activity. If the hard rock of the Eastern Mesabi containing only 20 to 30 per cent iron can be mined, crushed, and concentrated into merchantable ore, it is not difficult to believe that the vast amount of comparatively soft hematite containing from 35 to 45 per cent iron can first be rendered magnetic by roasting and then concentrated magnetically in the same manner as described above for Eastern Mesabi rock. It will be necessary for some group of men, having ample financial resources, to undertake the work of proving the possibilities of this method of treatment, exactly as the Mesabi Iron Company is doing with the magnetic ores.

ECONOMIC CONSIDERATIONS

It should be clearly understood, however, that the profit per ton that can be made by treating low-grade material will be very small, and only by handling immense tonnages will real success be assured. The state must realize this fact in connection with its taxation problems, and the property owners must understand that this ore material is worth nothing until it is manufactured into a merchantable product. They must, therefore, be content with small royalties. As a matter of fact, low-grade ore lands are seldom operated on a royalty basis, but an operating company is formed which buys the land outright. Often the land owner is paid with the stock of the company, and takes his profit out of the

earnings of the company. This would seem to be the fairer method, as the fee owner is certainly not entitled to an assured profit while the operating company, having a considerably larger investment, is taking all the risk.

In considering the situation as a whole, it seems that the people of the Lake Superior mining district are certainly to be congratulated upon their past accomplishments and upon the bright outlook for the future. The low-grade iron-ore industry is beginning, just as it should, long before the merchantable ores have been exhausted. The state of Minnesota need have no fear of an iron-ore shortage or a barren waste of abandoned mining lands. The iron-ore industry will be thriving in this district as long as iron and steel are useful metals, provided careful and exhaustive study of the treatment of low-grade material continues and all possible encouragement is given to this important industry by state and federal authorities.

If there is any criticism to be passed upon the mining men of Lake Superior district it is that they have kept their achievements too much to themselves. They have been satisfied to make a large amount of worthless land extremely valuable, and have not taken the trouble to explain their work to the people at large. This is a period of great publicity, and large advertising, and the mining industry must realize this fact in order to keep abreast of the times.



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